

VISUAL MINIMA TIMINGS OF ECLIPSING BINARIES: TO USE OR NOT TO USE?

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Abstract. Plenty of mid-eclipse timings of short-periodic eclipsing binaries derived from series of visual observations appear to be an acceptable source of information for orbital period analyses, namely if they were done in time-intervals not covered by other types of observations. However, our thorough period analysis of the nearly contact eclipsing binary BS Vulpeculae proves that visually determined timings done in 1979-2003 were undoubtedly biased to accommodate the existing linear ephemeris. The heavily subjective character of visual observations disqualifies them as a source of true phase information apt for fine eclipsing binary period analyses. Consequently we warn against the use of visual timings without a preceding careful verification.

Key words: eclipsing binaries - minima timings - visual observation - BS Vul

1. Introduction

There are many good reasons for the analysis of orbital periods of eclipsing binaries hereafter EBs). Many of the mysterious, astrophysically interesting binaries were revealed thanks to the analysis of their odd orbital period variations. Fine period analysis provide additional information about variable stars physics. By means of period analysis, it is possible to reveal and characterise the existence of further bodies in the EB system (stars, planets) or mass exchange between interacting binary components. By analysing period variations caused by apsidal motion we can deduce the internal structure of the components and test the theories of gravity. From the systematic decrease of the period of close EBs, it is possible to reason on the angular

momentum loss through stellar winds or gravitational waves, etc.

These period variations are always rather delicate. The credibility of conclusions based on EB period analysis depends strongly on the applied methods and reliability of the data used.

2. Data for period analyses of eclipsing binaries

There are two types of EB data, used together with phase information, that are standardly used for orbital period analysis – original time series of EB measurements (A) and mid-eclipse timings (B).

A. Various EB measurement time series types in the usual order of reliability are:

- photoelectric or CCD time series of parts of light curves done in several filters where EB minima are targeted or non-targeted;
- brightness measurements done by photometric surveys non-targeted to the particular object (ASAS, Hipparcos etc.);
- photoelectric or CCD time series of parts of light curves done in one filter or integral light where EB minima are targeted as a rule;
- time series of spectroscopic observations (line strengths, radial velocities etc.);
- time series of magnitudes derived from archival photographic plates;
- time series of individual visual estimates of EB brightness where eclipses are not targeted.

B. Timings of primary/secondary EB minima are preprocessed data derived from original time series of type A done as a rule during central parts of eclipses. The whole time series is then degenerated into only one result – time of the mid eclipse – derived standardly by an obsolete Kwee & van Woerden (1956) method. This method yields a usable estimate of minima times if descending and ascending branches are of the same length. Nevertheless, the uncertainties of minima timings were generally underestimated and consequently unacceptable.

Here follows eclipsing binary minimum light timing sources in order of their reliability:

- EB timings derived from photoelectric or CCD time series (a voluntary degradation from category A to B);
- timings when the EB was definitely fainter than in phases outside eclipses - an objective source of information, but of low quality;
- plenty of amateur visual observations of EB minima - a subjective source of information of problematic quality. Previously this was a most popular and respected amateur activity with a clear scientific output. The subjective source of information with problematic quality.

The only advantage of mid-eclipse timings (B) is the homogeneity of data from different observers and it is the main reason why the majority of period analyses were done using these types of data. However, a lot of such analyses are erroneous because of lowered reliability of entering data and the fact that times of minima almost do not use the fact that the light curves are periodical functions. Our experience is that the results of direct period analysis, based on time series of EB measurements (A), are at least twice as accurate.

3. Subjective nature of visual estimates of EB magnitudes

From our long, in-depth experience with visual observations of EBs it became clear that these data should be treated with caution since the data suffer from many bad attributes that effectively limit their suitability for fine period analysis purposes. We can enumerate only the most serious ones:

- Due to the poor quality of visual observations, the accuracy of the determined time of minimum light is much worse than for other types of photometric observations. The quality of visual timings are further deteriorated by the fact that some determinations were based on only a few individual observations done only in the immediate vicinity of the predicted time of minima (the majority of visual observation runs begin one hour before the expected minimum time and end one hour after it). The extreme shortness of observation runs are typical for some observers and one should be careful when using such unreliable minima timings (see the number of estimates used for minima timing determinations in the representative list of such data in Zhu et al., 2012).

- For time series of visual estimates, minimum light times were often determined by obscure, irreproducible methods. In the worst case, the original estimates were not published and they are now inaccessible.
- Almost all standard methods used to estimate mid-eclipse timings are based on the concepts of the least square method. However, this method strictly requires successive estimates to be independent. This requirement is definitely not kept in time series of visual observations. A ‘visual observer’ is not an instrument but a subject who knows what light curves of observed EBs should look like. He remembers his last estimates and subconsciously strives to create the most plausible light curve. ‘Observed’ visual light curves are thus subjectively smoothed to the ideal of theoretical or photoelectric light curves with clearly defined descending and ascending branches. This smoothing i.a. prevents us from estimating the real uncertainty of the timings’ determination from the time series of only one observing session. The uncertainties formally calculated and published from the smoothed light curve data are many times smaller than they should be.
- The most severe flaw in the majority of the visual observations is that observers obviously knew the predicted time of minimum light to an accuracy of minutes. If the ephemeris for the time of minimum light was incorrect, most observers were influenced into confirming the predicted, incorrect time of minimum light. This subjective effect, which is able to completely invalidate observations, equally afflicts both beginners and ‘experienced’ visual observers.

All these statements can be exemplary documented for the case of eclipsing binary BS Vulpeculae.

4. BS Vulpeculae

BS Vul is a relatively bright, but neglected nearly contact EB with very short orbital period $P \sim 0.476$ d. Zhu et al. (2012) recently analysed the period by the ‘direct’ period analysis method (briefly described in Mikulášek et al., 2012a) using 8177 individual brightness observations of BS Vul done during the time-interval 1898-2010. They found that the period is shortening. The result proves that BS Vul evolves toward contact phase.

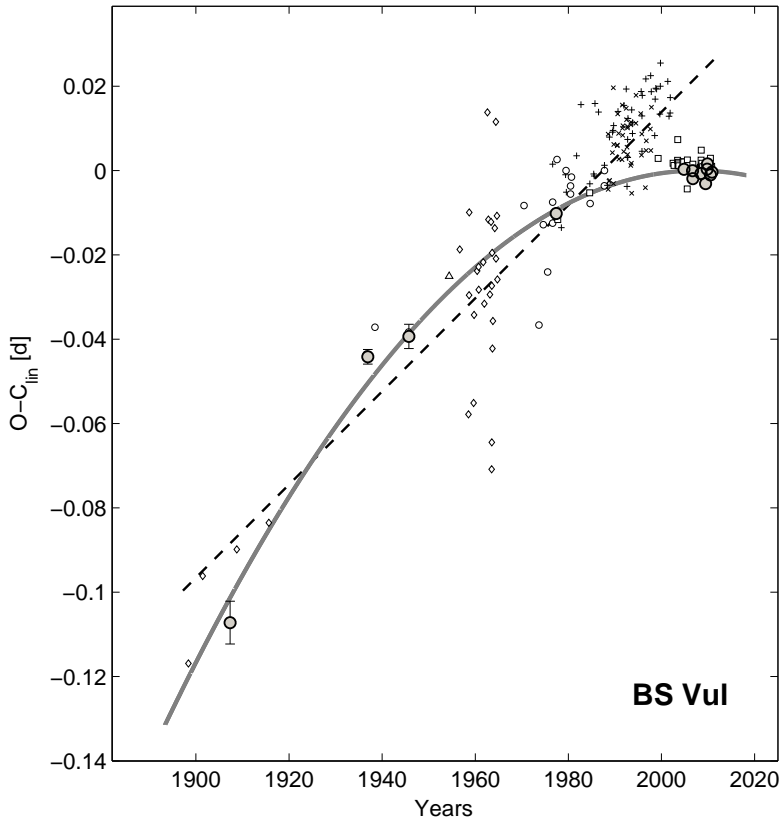


Figure 1: (O-C) diagram with respect to the linear ephemeris of primary minima times: $JD_1 = 2454387.8692 + 0.47597003 \times E$, where E is an integer (epoch). Large circles with error bars correspond to ‘virtual times of eclipses’ (Mikulášek et al., 2012a). The small symbols ‘+’ show published minima timings of visual observations of G. Samolyk, ‘x’ denote timings of H. Peter, and small circles correspond to minima obtained by other visual observers. Small diamonds are timings of photographic plates on which the star is close to minimum and small squares are photoelectric or CCD minima timings. The dashed line corresponds to the linear ephemeris of de Bernardi & Scaltriti (1979) $JD_1 = 2443271.578 + 0.47597147 \times E$, used by visual observers. The bold grey line corresponds to the found quadratic ephemeris.

Later we improved the method used in Zhu et al. (2012) so that it is now possible to combine all the above mentioned data with 46 mid-eclipse timings derived from time-series obtained by objective photometric measurements (photoelectric photometry, CCD photometry or acquiring of photographic snaps series) in a time vicinity of the predicted minima listed in Zhu et al. (2012). We confirmed the shortening of the orbital period and improved its value to $\dot{P} = -2.11(5)$ ms/yr (see also (O-C) diagram in Fig. 1).

4.1. BS VUL VISUAL MINIMA TIMINGS

The sufficiently deep primary eclipse (in visual 0.7 mag) and short duration (only 3.5 h) predestined BS Vul to be an attractive target for visual observers. We found in literature 104 primary mid-eclipse timings derived from visual observations in the time-interval 1970–2003 (see the list in Zhu et al., 2012). The large number of visual timings enables a relatively detailed discussion of their properties.

Our analysis of all 104 visual timings shows their excellent correlation with the linear ephemeris of de Bernardi & Scaltriti (1979) $JD_I = 2443271.578 + 0.47597147 \times E$, that was generally used by visual observers for their observation schedule (Fig. 2). The linear fit of visual observations is almost parallel with the line of prediction, while timings of minima systematically lag behind the minimum forecast by several minutes. Visual observations have only a very weak correlation with the real quadratic ephemeris. The conclusion is obviously valid for almost all visual observers who targeted the star. It is apparent that practically all visual observers subjectively adjusted their observations to more or less confirm the existing ephemeris. The systematic deflections had grown to 26 minutes by 2003.

The apparent ‘delay’ in visual observers’ timings with respect to prediction agrees well with the heliocentric corrections for the times of observation. Observers used geocentric time, but the predicted minimum light time was heliocentric, which was (in the case of BS Vul) delayed several minutes with respect of the geocentric time on the night when observations were done.

The most active visual observer of BS Vul G. Samolyk, published also 528 brightness estimates (accessible through the AAVSO webpage) obtained during his observations of 39 primary eclipses of BS Vul in the time interval 1984–2002.

We analysed all these data in detail and arrived i.a. at the following

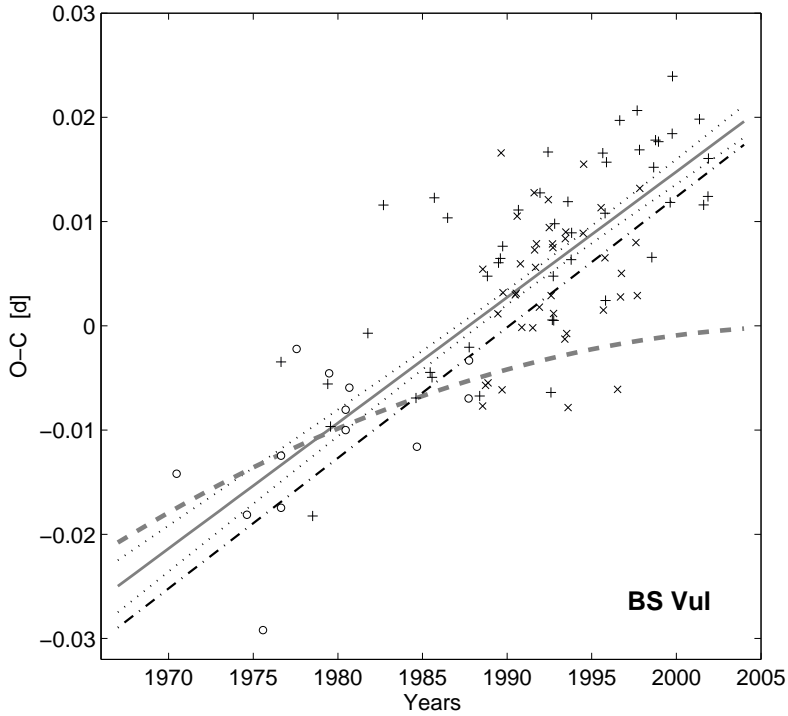


Figure 2: (O-C) diagram of visually determined primary eclipse timings with respect to the linear ephemeris $JD_1 = 2454387.8692 + 0.47597003 \times E$, where E is an integer (epoch). The symbols '+' show G. Samolyks' timings, 'x' denote H. Peters' timings, and circles correspond to timings obtained by other visual observers. The dashed-dotted line corresponds to the linear ephemeris of de Bernardi & Scaltriti (1979) $JD_1 = 2443271.578 + 0.47597147 \times E$, used by visual observers. The dashed curve is the real quadratic course. The full line is the linear fit of visually determined timings; dotted lines are the $1-\sigma$ uncertainty of this fit.

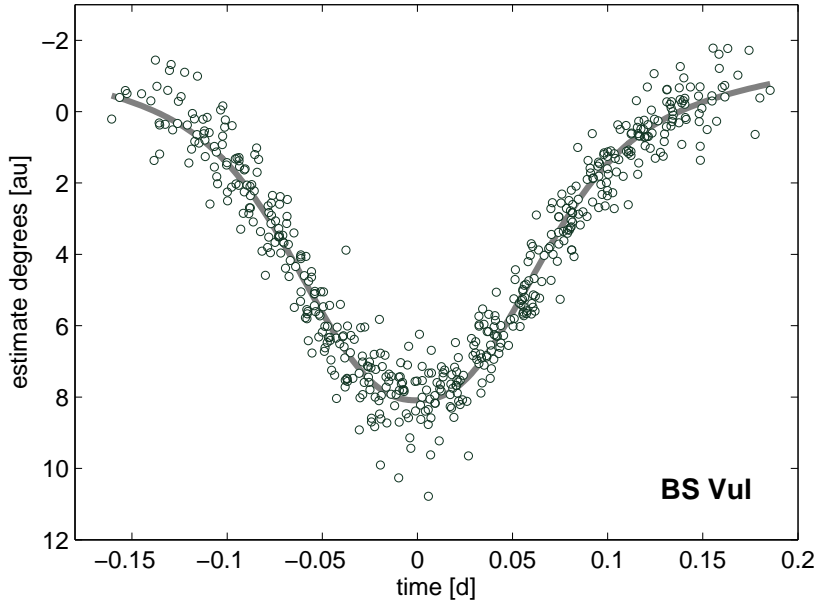


Figure 3: Samolyk’s mean light curve of the BS Vul primary minimum depicting his brightness estimates in arbitrary units versus the times of minima determined by him looks very authentically.

conclusions:

- Observations of BS Vul were (due to its extremely short period) always optimally scheduled, typically 12 estimates per eclipse were able to describe the complete eclipse quite well. Both descending and ascending branches of the light curve during eclipses were covered nicely.
- The resulting light curves were perfectly symmetric and they corresponded very well with ideal photometrically acquired curves (see Fig. 3). Samolyks’ light curves were very smooth; their scatter derived from the form of the light curve is only 0.055 mag! However, the scatter of individual times of eclipses indicates that the real scatter in estimates should be at least five times larger!

- The scatter of timings published by Samolyk and their bad affinity to the real quadratic ephemeris might have been caused by the application of an inappropriate method for the derivation of light curve minima from estimate series. Since we know the light curve shape, we applied our own rigorous method (Mikulášek et al., 2012b) to determine the times of minima. Although we obtained diverse times of minima, all of them were clustered around the de Bernardi & Scaltriti (1979) ‘geocentric’ ephemeris. Consequently, the estimates themselves were biased to accommodate the forecast.

It is evident from our findings that the heavily subjective character of visual observations of short period EBs disqualifies them as a source of unbiased information apt for fine EB period analysis. On the other hand we could use 200 visual estimates of brightness made by S. Piotrowski in two time intervals 1935–1939 (155 estimates) and 1945–1946 (45 estimates) (data in Szafraniec, 1962), because these estimates have a different character than later AAVSO and BBSAG visual observations. The distribution of these old visual estimates shows that they were obtained in ‘monitoring mode’ without the primary aim to obtain minima timings. Furthermore they passed our careful analysis.

5. Conclusion

Our analysis of mid-eclipse timings of BS Vul derived from the time series of visual observations proved the heavily subjective character of visual observations of BS Vul. It should be noted that mid-eclipse timings derived from observations of visual observers associated with B.R.N.O in pre-email times were not biased by the knowledge of the expected minima times of EBs. The reason for this is that they used special forecasts of EB minima distributed from the centre where times were rounded to the nearest half hour.

We conclude that the heavily subjective character of visual observations disqualifies visual minima timings as a source of true phase information necessary for fine eclipsing binaries period analyses. Consequently we do not advise using these data without having done a detailed verification of their reliability.

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